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(54) **OPTICAL SEMICONDUCTOR DEVICE HAVING WAVEGUIDE LAYERS BURIED IN AN INP CURRENT BLOCKING LAYER**

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(52) **U.S. Cl.** **372/50**; 372/26; 372/45; 372/46; 372/96

(58) **Field of Search** 372/26, 45, 46, 372/50, 96

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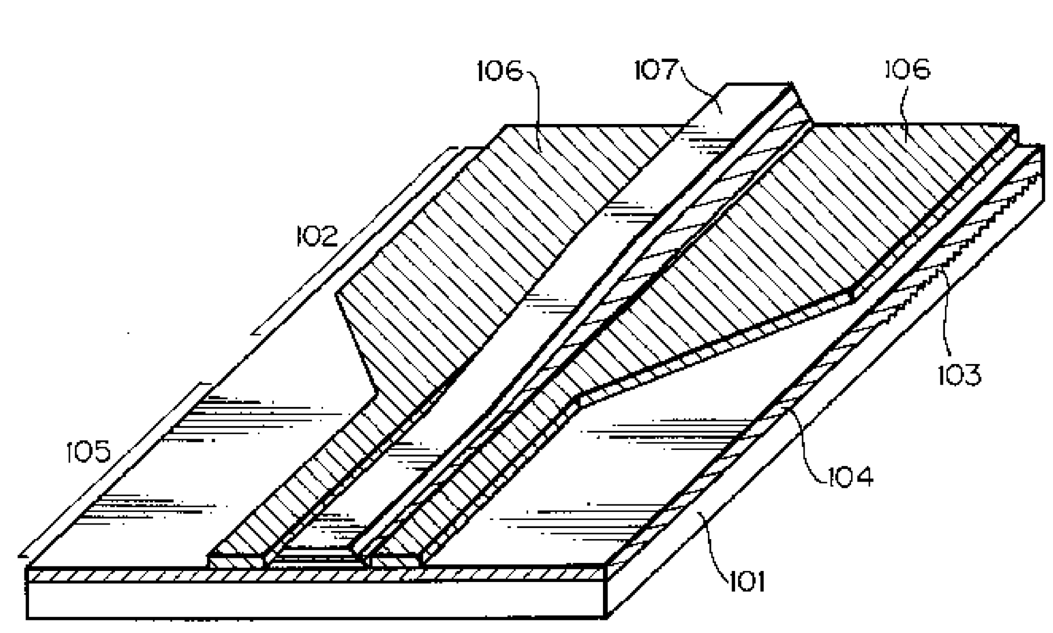
(57) **ABSTRACT**

An integrated semiconductor laser produced by forming waveguide layers each having a particular band gap and a particular layer thickness collectively and then forming an InP current blocking layer. After an InGaAsP layer has been formed on an InP substrate, a waveguide including a multiple quantum well active layer is formed by selective MOVPE. Then, the waveguide is buried in an InP current blocking layer. In this configuration, the current blocking layer exhibits its expected function without regard to the width of SiO_2 stripes used for selective metalorganic vapor phase epitaxial growth (MOVPE). The laser is feasible for high output operation and can be produced at a high yield.

8 Claims, 3 Drawing Sheets



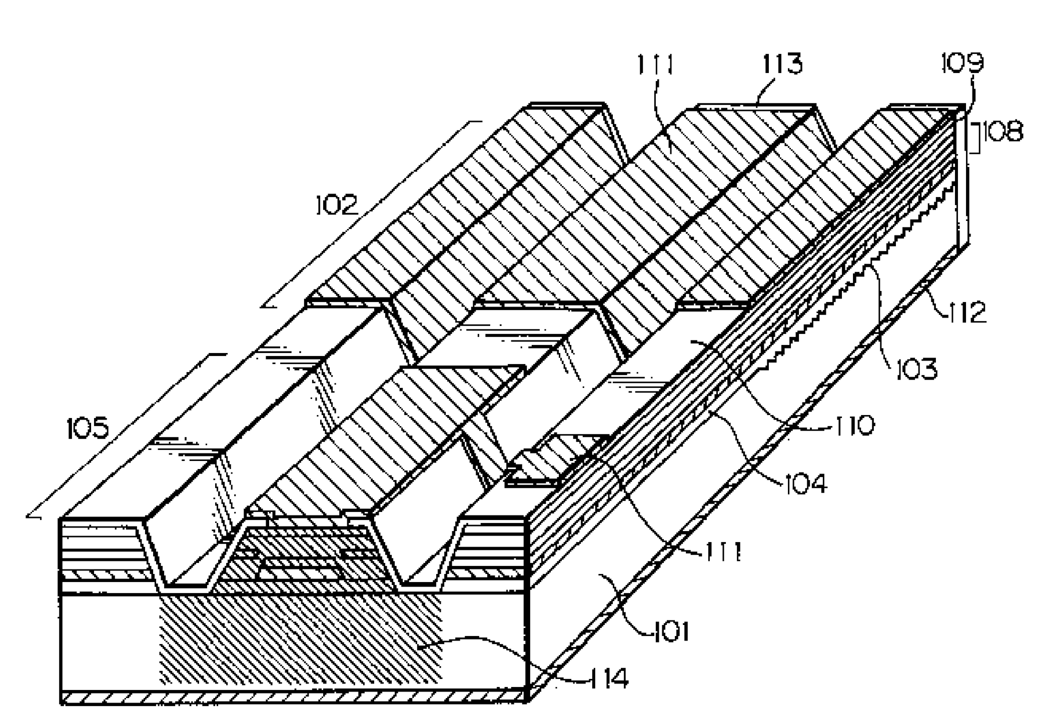


Fig. 1 PRIOR ART

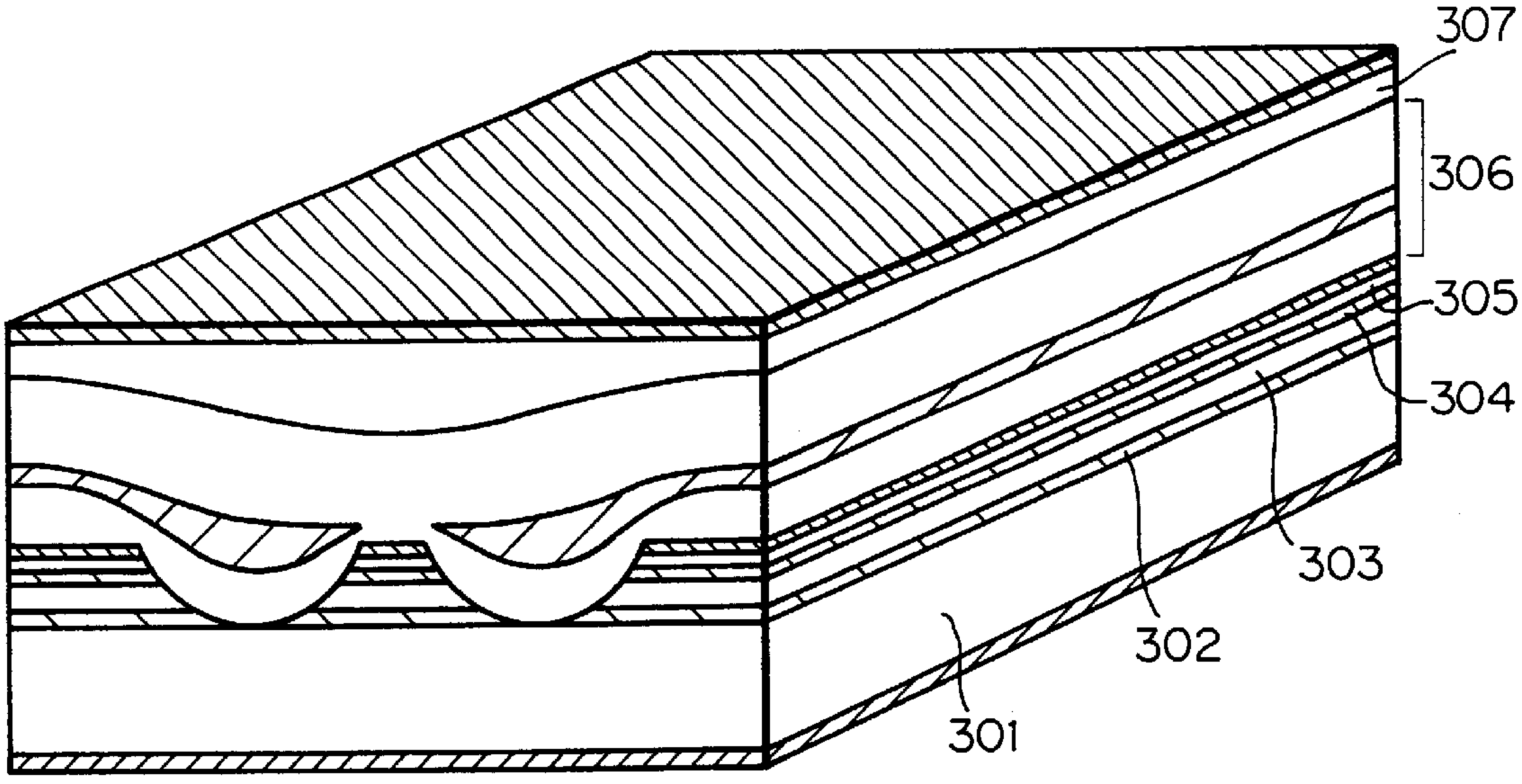


Fig. 2 PRIOR ART

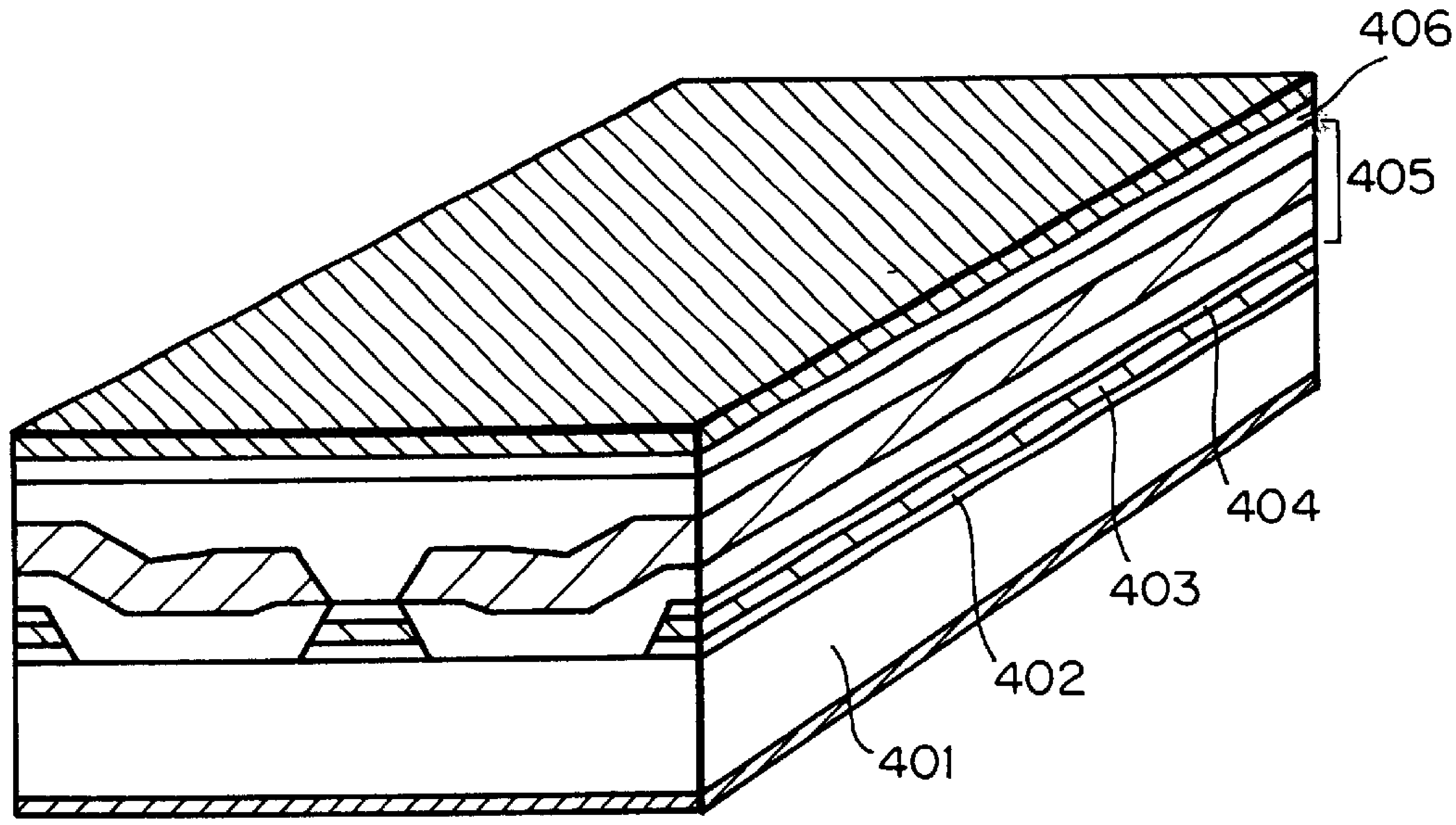
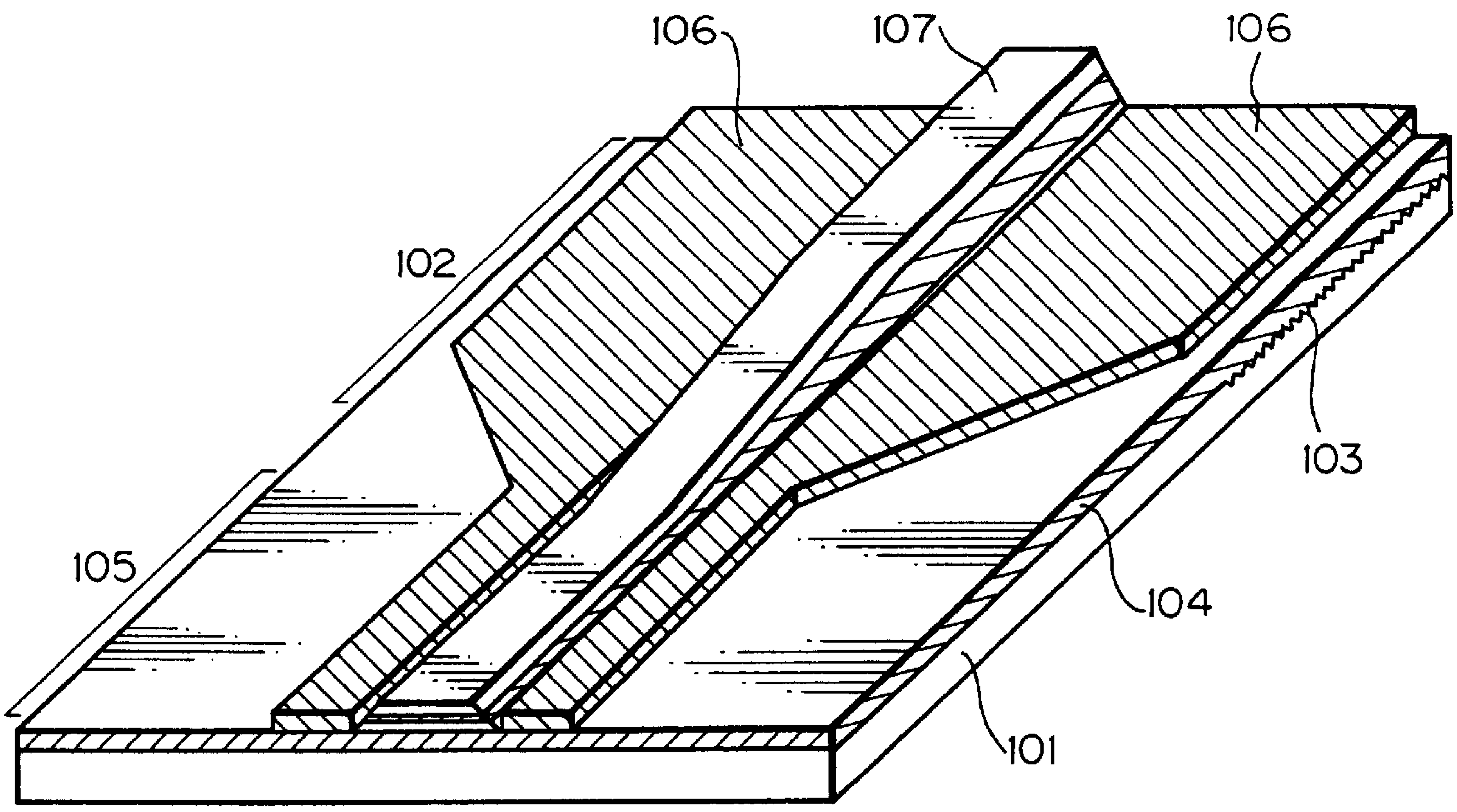


Fig. 3A


106
107
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104
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Fig. 3B

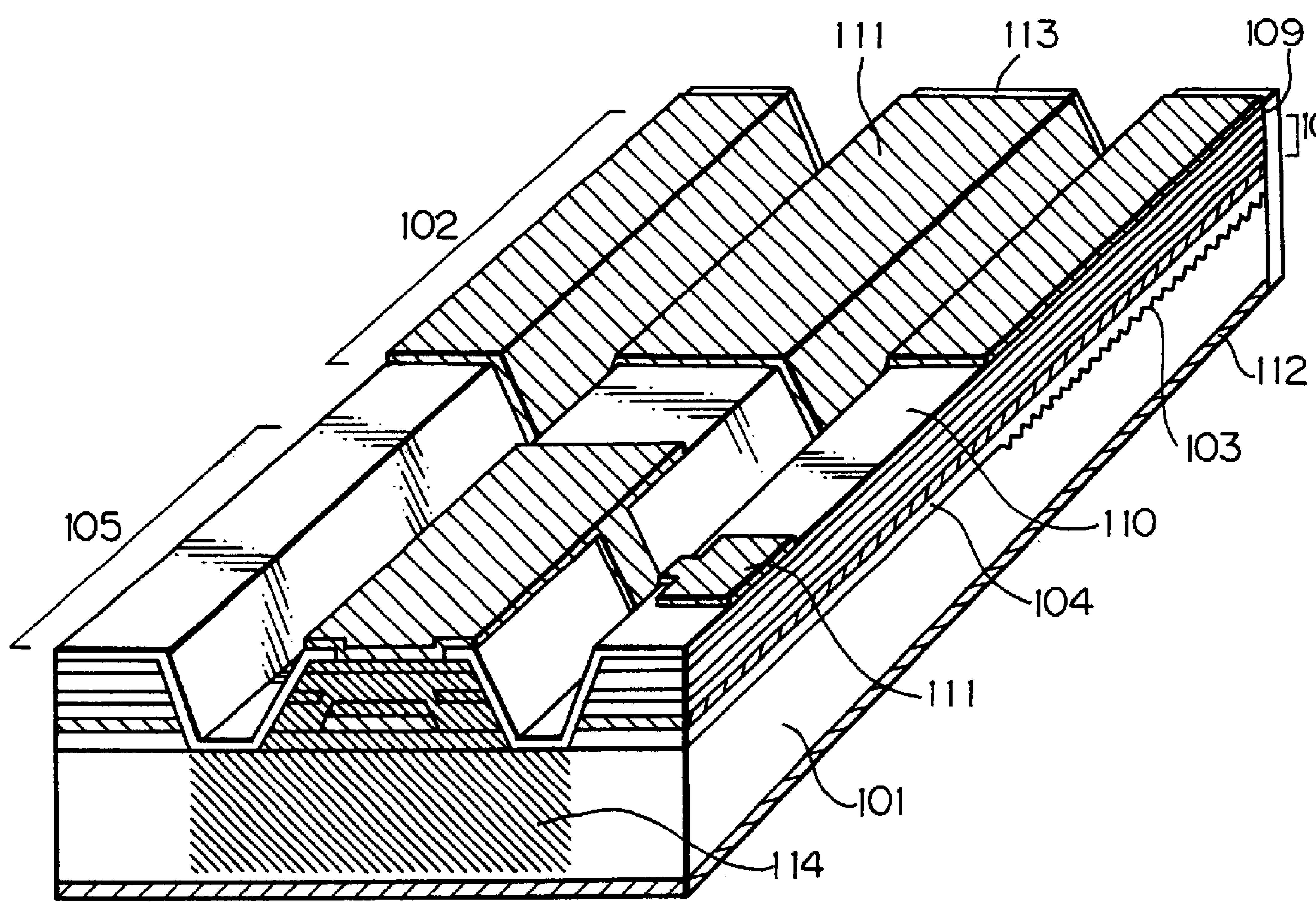
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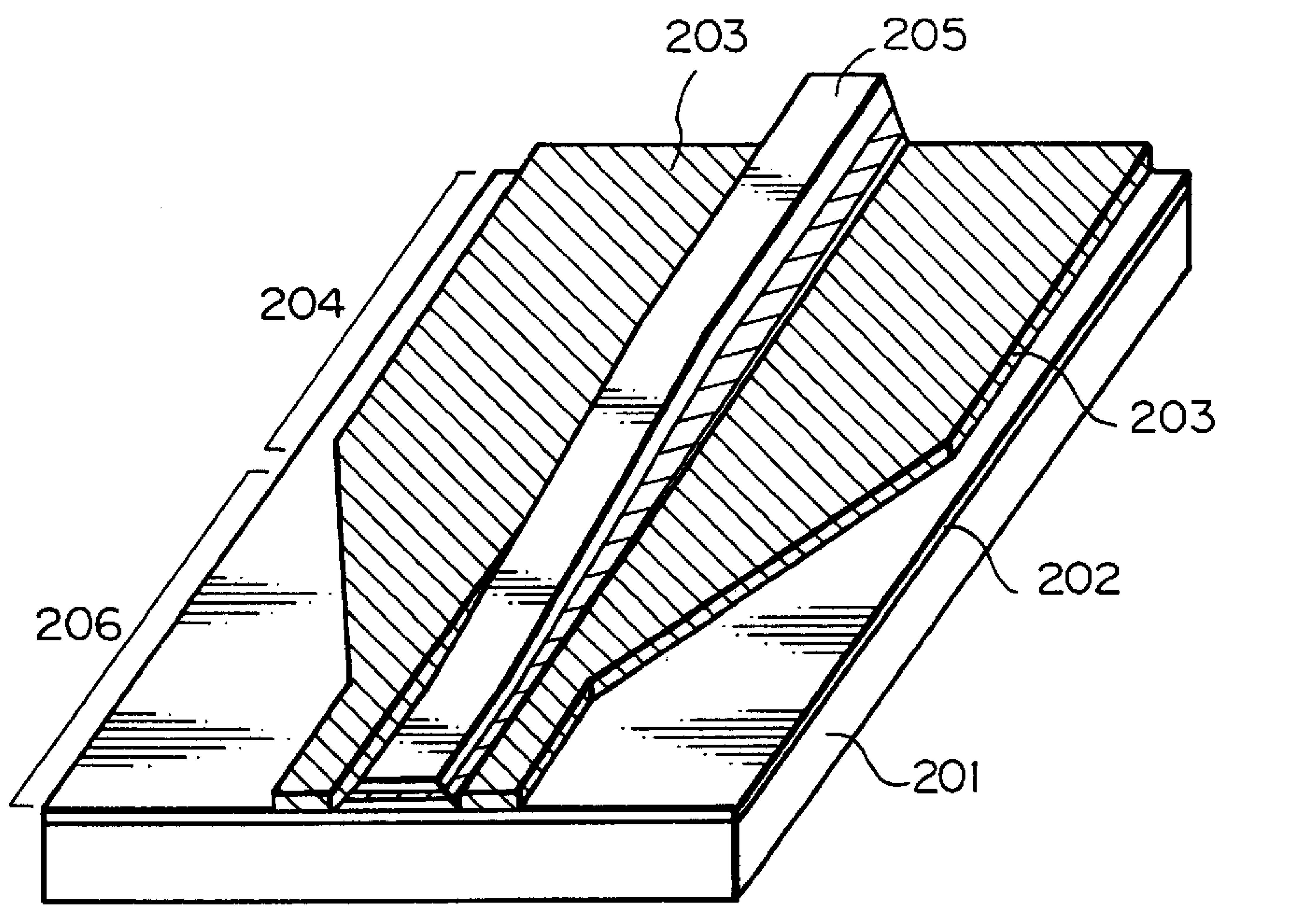
Fig. 4A


203
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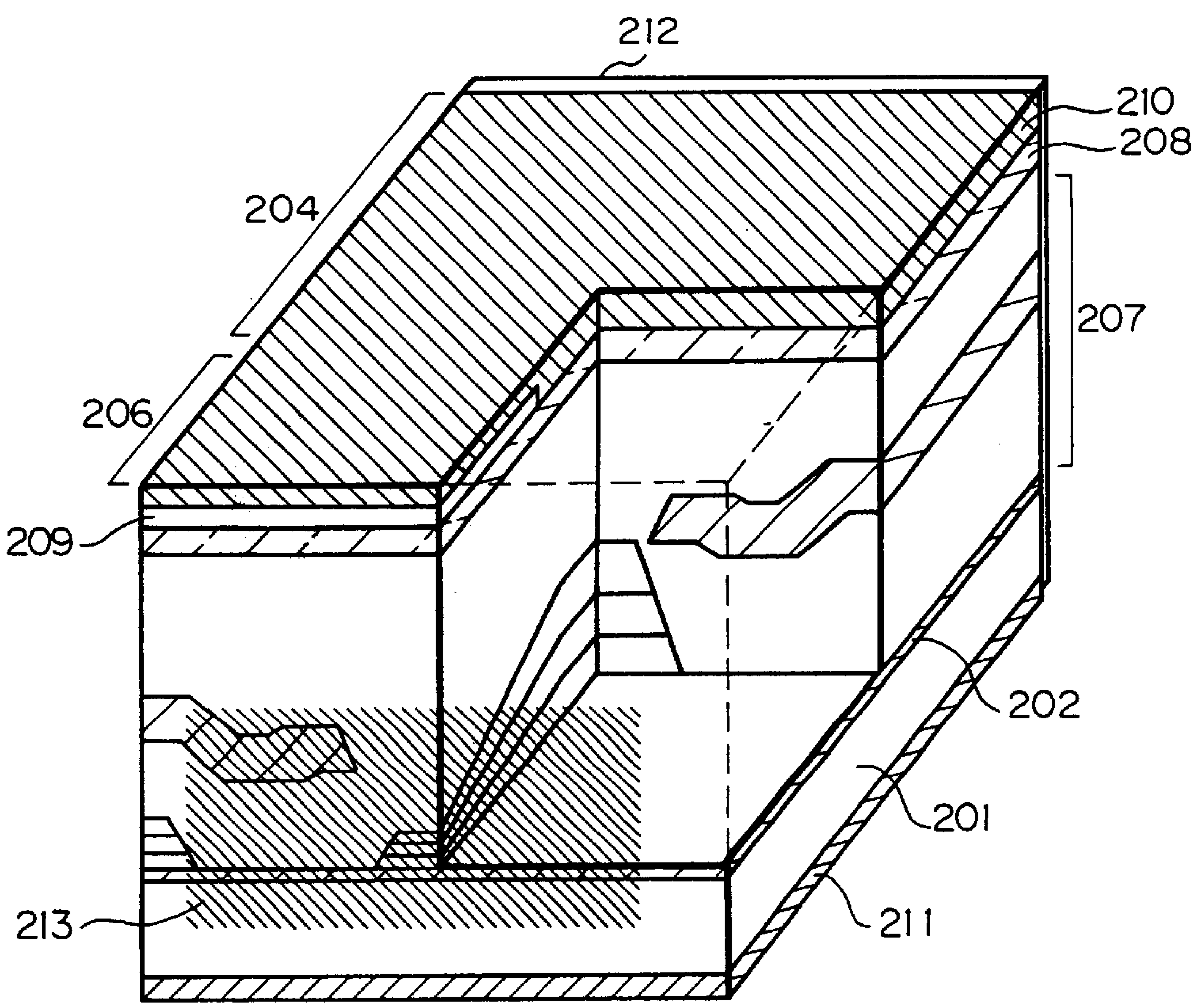
204
203
202
206
201

Fig. 4B


212
210
208
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206
209
202
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211

OPTICAL SEMICONDUCTOR DEVICE HAVING WAVEGUIDE LAYERS BURIED IN AN INP CURRENT BLOCKING LAYER

BACKGROUND OF THE INVENTION

The present invention relates to an optical semiconductor device and a method of producing the same and, more particularly, to an integrated semiconductor device feasible for high temperature or high optical output operation because of a minimum amount of current leak to occur from its current blocking layer, and a method of producing the same.

Today, the applicable range of optical communication is extending from trunk lines to branch lines or even to access lines. Semiconductor lasers for optical communication are therefore required to have advanced performance and new functions. For a trunk line, for example, a semiconductor laser whose drive spectrum involves a minimum of jitter at the time of modulation is essential in order to implement high speed, long distance transmission. A distributed feedback (DFB) laser having an electro absorption type optical modulator integrated therewith is one type of semiconductor laser meeting the above requirement. As for an access line, there is an increasing demand for a semiconductor laser to be easy to mount and capable of being efficiently coupled to an optical fiber. This kind of laser may be typified by a so-called spot size conversion type laser including a portion for converting the size of a beam.

Japanese Patent Laid-Open Publication No. 62-102583, for example, teaches a semiconductor laser desirable in high temperature or high optical output characteristic. However, the problem with the laser taught in this document is that the characteristic and yield are limited for the following reasons. To form layers different in band gap and thickness on a single substrate, crystal growth and crystal etching must be repeated, increasing the number of steps. Moreover, it is difficult to connect waveguides different in band gap and thickness accurately. As a result, a light loss occurs at the connecting portion and deteriorates the optical output characteristic.

To implement an integrated semiconductor laser, selective metalorganic vapor phase epitaxial growth (MOVPE) procedure capable of forming waveguide layers different in band gap and thickness collectively is attracting increasing attention. A semiconductor laser produce by selective MOVPE is disclosed in, e.g., the Papers of 56th Japanese Science Lecture Meeting, 1995, 27p-ZA-7, p. 930. This kind of scheme, however, brings about a problem that a current blocking layer included in the laser cannot function sufficiently in a high temperature environment or on the injection of a great current. Specifically, while a laser portion usually has the smallest band gap, it is necessary with selective MOVPE to increase the width of an anti-growth mask in the waveguide portion where the band gap should be reduced, i.e., the laser portion. It follows that in the laser portion the current blocking layer implemented only by InP and having a p-n-p-n thyristor structure has a broad area at both sides of an active layer. As a result, current leakage from the current blocking layer and ascribable to the storage of electrons is aggravated.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an integrated semiconductor laser feasible for high temperature or high output operation, and a method of producing the same.

In accordance with the present invention, in an optical semiconductor device having an electro absorption type modulator and a DFB laser in an integrated structure, the modulator and laser are formed on an InP substrate formed with an InGaAsP layer, and waveguide layers respectively functioning as the modulator and laser are buried in an InP current blocking layer.

Also, in accordance with the present invention, in an optical semiconductor device including a laser having a spot size converting portion integrally therewith, the laser is formed on an InP substrate formed with an InGaAsP layer, and waveguide layers respectively functioning as the laser and spot size converting portion are buried in an InP current blocking layer.

Further, in accordance with the present invention, a method of producing a semiconductor device has the steps .of forming two SiO_2 stripes on an InP substrate formed with a n InGasP layer, and forming a waveguide including a multiple quantum well active layer by selective MOVPE between the two stripes, and burying the waveguide in an InP current blocking layer.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become apparent from the following detailed description taken with the accompanying drawings in which:

FIG. **1** shows a conventional semiconductor laser having an improved high temperature or high optical output characteristic;

FIG. **2** shows another conventional semiconductor laser implemented by selective MOVPE;

FIGS. **3**A and **3**B show a semiconductor laser embodying the present invention and implemented as a DFB laser including a semiconductor modulator integrally therewith; and

FIGS. **4**A and **4**B show an alternative embodiment of the present invention and implemented as an integrated semiconductor laser including a spot size converting portion.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

To better understand the present invention, brief reference will be made to a conventional semiconductor laser featuring an improved high temperature or high optical output characteristic, shown in FIG. **1**. The laser to be described is taught in Japanese Patent Laid-Open Publication No. 62-102583 mentioned earlier. As shown, the laser includes a (100)n-InP substrate **301**. An n-InGaAsP carrier recombination layer **302**, an n-InP cladding layer **303**, an InGaAsP active layer **304** and a p-InP cladding layer **305** are sequentially formed on the substrate **301** by liquid phase epitaxial growth (LPE hereinafter). Two parallel grooves reaching the recombination layer **302** are formed in a <011> direction, implementing a mesa stripe. Subsequently, a p-InP/n-InP/p-InP current blocking layer **306** having a thyristor structure and a p-InGaAsP cap layer **307** are formed by LPE.

The current blocking layer **306** includes a carrier recombination layer implemented by InGaAsP having a smaller band gap than InP. With the blocking layer **306**, the semiconductor laser restricts the storage of electrons in the n-InP blocking layer during high temperature operation or high optical output operation. This successfully obviates the turn-on of the current blocking layer **306** having the p-n-p-n thyristor structure. However, the configuration shown in

FIG. **1** results in limited yield and limited optical output characteristic for the reasons discussed earlier.

FIG. **2** shows another conventional semiconductor laser which is produced by selective MOVPE. As shown, the laser includes a (100)n-InP substrate **401**. A pair of SiO_2 (silicon dioxide) stripe masks are formed on the substrate **401** at an interval of 5 μm in a <011> direction. Then, an n-InP buffer layer **402**, an active layer **403** formed of InGaAsP and having a multiple quantum well (MQW layer hereinafter) structure, and an active stripe implemented by a p-InP cladding layer **404** are formed by selective MOVPE. Subsequently, a current blocking layer **405** implemented as a p-InP/n-InP/p-InP layer and having a thyristor structure and a p+-InGaAs cap layer **406** are formed. This kind of laser configuration is disclosed in the Papers of 56th Japanese Science Lecture Meeting, 1995, 27p-ZA-7, p. 930.

The laser shown in FIG. **2** allows its SiO_2 stripe mask width to be modulated in order to change the band gap and/or thickness of the MQW layer. It is therefore possible to form waveguides each having a particular function by a single crystal growth. However, the problem is that the current blocking layer **405** cannot exhibit its expected function in a high temperature environment or on the injection of a large amount of current.

Referring to FIGS. **3A** and **3B**, a semiconductor device embodying the present invention is shown and implemented as a DFB laser having an integrated field electro type modulator integrally therewith by way of example. As shown, the DFB laser includes a (100) orientation n-InP substrate **101** having a laser portion **102** and a modulator portion **105**. A procedure for producing the DFB laser will be described first. The laser portion **102** of the substrate **101** is formed with a corrugation **103** in a <011> direction by holographic exposure and wet etching. The corrugation **103** has a period of 241.7 nm. An InGaAsP layer **104** is formed on the laser portion **104**, including the corrugation **103**, by MOVPE at a pressure of 75 Torr and a temperature of 625° C. The InGaAsP layer **104** has a thickness of 0.1 μm, a carrier concentration of $5\times10^{1\ 7}$ cm^{-3}, and a band gap wavelength of 1.13 μm. Anti-growth masks **106** are formed on the InGaAsP layer **104**. Specifically, after SiO_2 has been deposited on the InGaAsP layer **104** in a 150 nm thick layer by thermal CVD, the SiO_2 layer is patterned by conventional photolithography and wet etching in order to form the anti-growth masks **106** in the <011> direction. The masks **106** are spaced by 1.5 μm, and each is 18 μm wide and 500 μm long in the laser portion **102** and 5 μm wide and 200 μm long in the modulator portion **105**.

Subsequently, an eight-period MQW active layer, an InGaAsP light confining layer and a p-InP cladding layer are sequentially formed by selective MOVPE at a pressure of 75 Torr and a temperature of 625° C. in order to form a waveguide mesa **107**. The MQW active layer is made up of a 6 nm thick 0.5% compressively strained InGaAsP well layer and an 8 nm thick barrier layer having a band gap wavelength of 1.13 μm. The InGaAsP light confining layer is 60 nm thick and has a carrier content of 5×10^{17} cm^{-3} and a band gap wavelength of 1.13 μm. The p-Inp cladding layer is 0.1 μm thick and has a carrier concentration of 5×10^{17} cm^{-3}. As a result, the waveguide mesa **107** is formed such that it has a band gap wavelength composition of 1.56 μm in the laser portion **102**.

At this instant, the MQW layer in the modulator portion **105** has a band gap wavelength of 1.47 μm. After the anti-growth masks **106** have been removed, SiO_2 is deposited on the entire wafer to a thickness of 300 nm in the form of mesas. Then, the SiO_2 layer is processed by photolithography and wet etching to turn out an SiO_2 pattern.

Thereafter, a 0.3 μm thick p-InP layer having a carrier concentration of 5×10^{17} cm^{-3}, a 1 μm thick n-InP layer having a carrier concentration of 1×10^{18} cm^{-3}, and a 0.2 μm thick p-InP layer having a carrier concentration of 5×10^{17} cm^{-3} are sequentially formed by selective MOVPE at a pressure of 75 Torr and a temperature of 625° C. After the SiO_2 mask has been removed, a 1.5 μm thick p-InP layer having a carrier concentration of 1×10^{18} cm^3 is formed by MOVPE at a pressure of 75 Torr and a temperature of 625° C. in order to form a current blocking layer **108** having a thyristor structure. A 0.2 μm thick InGaAs cap layer **109** having a carrer concentration of $5\times10^{1\ 8}$ cm^{-3} is formed on the current blocking layer **108**.

After 10 μm wide mesa stripes have been formed by wet etching, SiO_2 **110** is deposited to a thickness of 350 nm and then subjected to conventional photolithography and wet etching in order to form contact holes. Then, Ti and Au are respectively deposited to a thickness of 100 nm and a thickness of 300 nm by sputtering and then subjected to conventional photolithography and wet etching so as to form p-electrodes or pads **111** in the modulator portion **105** and laser portion **102**. After the wafer with such a configuration has been ground to a thickness of 100 μm, Ti and Au are respectively deposited on the rear of the wafer to a thickness of 100 nm and a thickness of 300 nm by sputtering in order to form an n-electrode **112**. The wafer undergone the above procedure is sintered in an N_2 atmosphere.

Finally, the wafer is cleaved at the center between the laser portion **102** and the modulator portion **105**. A reflection film **113** whose reflectance is as high as 90% and a reflection film **114** whose reflectance is as low as 0.1% are respectively formed on the end face of the laser side and the end face of the modulator side.

The laser produced by the above procedure was found to implement an optical output of 50 mW, which is double the a conventional optical output, at drive thresholds of 8 mA and 200 mA. Further, when a reverse bias voltage of 2 V is applied to the modulator, an extinction ratio of higher than 15 dB was attained. Moreover, a penalty of less than 1 dB w a s achieved as a result of a transmission test using a modulation rate of 2.5 Gb/s and a 150 km long normal fiber.

An alternative embodiment of the present invention will be described with reference to FIGS. **4A** and **4B**. This embodiment is implemented as a semiconductor laser with a spot size converting portion. As shown, the laser includes a (100) orientation n-InP substrate **201**. How the laser is produced will be described first. A 60 nm thick InGaAsP layer **202** whose carrier content is 5×10^{17} cm-3 and band gap wavelength is 1.05 μm is formed on the substrate **201** by MOVPE at a pressure of 75 Torr and a temperature of 625° C. After SiO_2 has been deposited to a thickness of 150 nm by thermal CVD, it is subjected to conventional photolithography and wet etching in the <011> direction in order to form anti-growth masks **203**. The anti-growth masks **203** are spaced by 1.5 μm, and each is 60 μm wide and 300 μm long in a laser portion **204** and 50 μm to 5 μm wide and 200 μm long in a spot size converting portion **206**; the width in the portion **206** gradually varies in the above range.

Subsequently, a seven-period MQW active layer, an InGaAsP light confining layer and a p-InP cladding layer are sequentially formed by selective MOVPE at a pressure of 75 Torr and a temperature of 625° C in order to form a waveguide mesa **205**. The MQW active layer is made up of a 4 nm thick 1% compressively strained InGaAsP well layer and an 8 nm thick barrier layer having a band gap wavelength of 1.13 μm. The InGaAsP light confining layer is 60 nm thick and has a carrier concentration of 5×10^{17} cm^{-3} and a band gap wavelength of 1.13 μm. The p-InP cladding layer is 0.1 μm thick and has a carrier concentration of 5×10^{17} cm^{-3}. As a result, the waveguide mesa **205** is formed such that it has a band gap wavelength composition of 1.3 μm in the laser portion **204**. At this instant, each layer is gently reduced in thickness to about one-third.

Sio_2 is deposited on the entire wafer to a thickness of 300 nm in the form of mesas. Then, the SiO_2 layer is processed by photolithography and wet etching to turn out an SiO_2 pattern. Thereafter, a 0.3 μm thick p-InP layer having a carrier concentration of 5×10^{17} cm^{-3}, a 1 μm thick n-InP layer having a carrier concentration of $1\times10^{1\ 8}$ cm^{-3}, and a 0.2 μm thick p-InP layer having a carrier concentration of 5×10^{17} cm^{-3} are sequentially formed by selective MOVPE at a pressure of 75 Torr and a temperature of 625° C. After the SiO_2 mask has been removed, a 4 μm thick p-InP layer having a carrier content of $1\times10^{1\ 8}$ cm^{-3} is formed by MOVPE at a pressure of 75 Torr and a temperature of 625° C. in order to form a current blocking layer **207** having a thyristor structure. A 0.2 μm thick InGaAs cap layer **208** having a carrier content of $5\times10^{1\ 8}$ cm^{-3} is formed on the current blocking layer **207**.

Thereafter, SiO_2 is deposited to a thickness of 350 nm and then subjected to conventional photolithography and wet etching in order to form contact holes. Then, Ti and Au are respectively deposited to a thickness of 100 nm and a thickness of 300 nm by sputtering and then subjected to conventional photolithography and wet etching so as to form p-electrodes or pads **210**. After the wafer with such a configuration has been ground to a thickness of 100 μm, Ti and Au are respectively deposited on the rear of the wafer to a thickness of 100 nm and a thickness of 300 nm by sputtering in order to form an n-electrode **211**. The wafer undergone the above procedure is sintered in an N_2 atmosphere.

Finally, the wafer is cleaved at the center between the laser portion **204** and the spot size converting portion **206**. A reflection film **212** whose reflectance is as high as 95% and a reflection film **213** whose reflectance is as low as 30% are respectively formed on the end face of the laser side and the end face of the spot size conversion side.

For a drive threshold of 6 mA and an optical output of 20 mW at room temperature, the illustrative embodiment was successful to drive the laser with a drive current of 40 mA. Particularly, at a temperature of 8 5° C and for an oscillation threshold of 15 mA and an optical output of 20 mW, the illustrative embodiment reduced the drive current to 75 mA which was more than 30% lower than the conventional drive current. Further, the laser emitted light with a radiation angle of 13°×13°, i.e., it achieved a desirable spot size conversion characteristic.

In summary, in accordance with the present invention, waveguide layers each having a particular layer thickness and a particular composition can be collectively formed by selective MOVPE. This allows integrated semiconductor lasers feasible for high temperature operation or high output operation to be produced at a high yield. Specifically, although an SiO_2 stripe mask width is modulated at the time of MOVPE in order to form the above waveguide layers, a current blocking layer capable of exhibiting a sufficient current blocking function without regard to the above width can be formed.

Various modifications will become possible for those skilled in the aft after receiving the teachings of the present disclosure without departing from the scope thereof.

What is claimed is:

1. An optical semiconductor device comprising:

an n-InP substrate having a laser portion and a modulator portion, the laser portion being formed with a corrugation;

an InGaAsP layer formed on a top surface of the n-InP substrate, wherein the lnGaAsP layer is formed in a region including the corrugation;

a waveguide mesa formed on both the laser portion and the modulator portion. the waveguide mesa being thicker in the laser portion than in the waveguide portion; and

an InP current blocking laver formed above and around the waveguide mesa,

wherein the waveguide mesa comprises:

an eight-period MQW active layer;

an InGaAsP light confning layer; and

a p-InP cladding layer,

wherein the InP current blocldng layer comprises:

a first p-InP layer having a first carrier concentration;

an n-InP layer having a second carrier concentration greater than the first carrier concentration, the n-InP layer being formed directly on the first p-InP layer;

a second p-InP layer having the first carrier concentration, the second p-InP layer being formed directly on the n-InP layer; and

a third pInP layer having the second carrier concentration, the third p-InP layer being formed directly on the second p-InP layer.

2. An optical semiconductor device as claimed in claim **1**, further comprising:

an InGaAs cap layer having a third carrier concentration greater than the second carrier concentration, the InGaAs cap layer being formed directly on the InP current blocking layer.

3. An optical semiconductor device as claimed in claim **2**, further comprising:

a first reflection film having a reflectivity percentage greater than a predetermined amount, the first reflection film being formed on an end face of the laser portion; and

a second reflection film having a reflectivity percentage less than the predetermined amount, the second reflection film being formed on an end face of the modulator portion.

4. An optical semiconductor device as claimed in claim **3**, wherein the reflectivity percentage of the first reflection film is approximately 90%, and wherein the reflectivity percentage of the second reflection film is approximately 0.1%.

5. An optical semiconductor device as claimed in claim **3**, furter comprising at least one pad formed on the cap layer.

6. An optical semiconductor device as claimed in claim **3**, further comprising an n-electrode formed against a bottom surface of the n-InP substrate.

7. In an optical semiconductor device having a laser and a spot size converting portion integrally therewith, said laser is formed on an InP substrate and formed with an InGaAsP layer. and waveguide layers respectively functioning as said laser and said spot size converting portion are buried in an InP current blocking layer that is formed above and around the waveguide layers,

wherein said InP current blocking laver is formed having a thyristor structure,

wherein the waveguide layers comprise:

a seven-period MOW active layer;

an InGaAsP light confining layer; and
a p-InP cladding layer,

wherein the InP current blocking layer comprises:

a first p-InP layer having a first carrier concentration;
an n-InP layer having a second carrier concentration greater than the first carrier concentration, the n-InP layer being formed directly on the first p-InP layer;
a second p-InP layer having the first carrier concentration, the second p-InP layer being formed directly on the n-InP layer; and
a third p-InP layer having the second carrier concentration, the third p-InP layer being formed directly on the second p-InP layer.

8. An optical semiconductor device as claimed in claim **7**, further comprising:

an InGaAs cap layer having a third carrier concentration greater than the second carrier concentration, the InGaAs cap layer being formed directly on the InP current blocking layer.

* * * * *